

VLHC Based ep Colliders: e-ring versus e-linac

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Abstract

Main parameters of a Linac*VLHC based ep collider are estimated and compared with recently suggested ep collider in the VLHC tunnel.

I. Introduction

The CERN Large Hadron Collider (LHC) and 50+50 TeV hadron collider (VLHC), sub-TeV (TESLA, JLC/NLC) and multi-TeV (CLIC) electron-positron colliders and multi-TeV energy muon collider (HEMC) are considered as energy frontiers for the 21st century high energy physics research [1]. On the other hand, the importance of lepton-hadron colliders is a matter upon which general agreement is made. Indeed, the quark-parton structure of the matter was discovered in lepton-hadron collisions. The first and unique operating electron-proton collider is HERA with $\sqrt{s} \approx 300$ GeV and $L \approx 10^{31} \text{ cm}^{-2}\text{s}^{-1}$. Nowadays, an addition of e-ring or e-linac to RHIC (eRHIC) is intensively discussed [2]. There are two proposals in achieving TeV scale, namely, LEP*LHC [3] and THERA [4], that can be taken seriously. Concerning multi-TeV scale in lepton-hadron collisions, the Linac*LHC based ep, γp , eA and γA colliders [5] are of the most realistic feature in contrast to speculative μp collider proposals.

There are a number of papers devoted to possible ep collider based on VLHC. Two options are evaluated [6]: ep collisions in VLHC booster ($\sqrt{s} = 1$ TeV and $L = 2.6 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$) and ep collisions in VLHC ring ($\sqrt{s} = 6$ TeV and $L = 1.4 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$). The first option is left untouched in this paper because of LEP*LHC and THERA covering the same region. For the second option, where the construction of $E_e = 180$ GeV e-ring in the VLHC tunnel is planned, we have two objections:

1. Linac*LHC with $\sqrt{s} = 5$ TeV and $L = 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ can be realized earlier and will give opportunity to an additional γp , eA and γA options.
2. Instead of constructing a 530 km e-ring it is more wise to construct a 10 km e-linac with the same parameters.

II. Linac*VLHC based ep colliders

Parameters of VLHC proton beam and electron beam in VLHC tunnel are presented in the second and third columns of Table 1. For e-linac options we consider TESLA [7] and the JLC/NLC [8] beams with 250 GeV. Corresponding parameters are given in last two columns of the Table.

Luminosity of ep collisions is calculated using:

$$L = \frac{n_e n_p}{4\pi\epsilon_t\beta^*} f_{coll}$$

where n_e and n_p are the numbers of electrons and protons in the corresponding bunches, ϵ_t is the transverse emittance of proton beam which is equal to ϵ_N/γ_p (ϵ_N is the normalized emittance and γ_p is the Lorentz factor for proton beam), β^* is amplitude function at the interaction region and f_{coll} is collision frequency which is equal to $n_b f_{rep}$ (n_b stands for number of bunches in electron pulse, f_{rep} is linacs repetition frequency) for linac-ring colliders and to $2\pi R/c k_b$ ($2\pi R$ is VLHC circumference, c is the speed of light, k_b is number of proton and electron bunches in ring) for ring-ring colliders.

In the case of linac-ring type colliders bunch spacing of electron linac should be adjusted to match with bunch spacing of proton ring. For the "TESLA" option, these spacing are of the same order, so the adjustment is not a particular problem. However for the "JLC/NLC" option the bunch spacing of electron beam (2.8 ns) is smaller than proton spacing in VLHC by orders. For this reason we consider the appropriate upgrade of JLC/NLC parameters, namely, number of bunches per pulse is lowered by an order ($95 \rightarrow 10$) with simultaneous increase in number of electrons per bunch ($10^{10} \rightarrow 10^{11}$). At the same time number of bunches in VLHC proton ring adjusted from 6000 to 60000.

For the luminosity evaluation we take ϵ_N and β^* to be 10^{-6} mrad and 10 cm, respectively. With these values we obtain $L_{ep} \approx 3 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ for "TESLA"*VLHC and $L_{ep} \approx 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ for "JLC/NLC"*VLHC.

In principle, the luminosity can be increased further using "dynamic focusing" [9] and/or cooling of proton beams. Applying both of these methods together, at least an order higher luminosity can be achieved.

III. Conclusion

A high energy lepton-hadron colliders will provide data crucial to exploration of the ultimate constituents of matter. Concerning the Standard Model, these machines will essentially enlarge our understanding of QCD, especially in the domain of small x_B and large Q^2 which is vital for confinement problem. The data will be used to interpret results from future high energy hadron colliders, also. In the field of BSM physics, there are a lot of phenomena that can be best investigated in lepton-hadron collisions, such as, leptoquarks and leptogluons, excited leptons (ν^* , e^*), sneutrino and sleptons etc. The γp option of future

linac-ring type lepton-hadron colliders, will essentially enlarge their physics research potential. Indeed, photon-hadron colliders are the best machines for investigation of small x_g region via pair production of heavy quarks, associated production of sneutrino and squarks, resonant production of excited quarks etc (For more details on the subject see review [10]).

As a result, future lepton-hadron colliders (see Table 2) will be complementary to future hadron and lepton colliders. In near term future different upgrades of the HERA (luminosity, polarized protons, nuclear beams) and eRHIC machines promise valuable results. Concerning TeV scale, the THERA (TESLA*HERA) can be the first machine and Linac*LHC should be considered seriously as the next step. As mentioned above, an additional options of THERA and Linac*LHC, namely, γp , eA and γA colliders extend considerably their physics research potential. As for far term future, Linac*VLHC (rather than e-ring in VLHC tunnel) requires more serious consideration.

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Table 1. Main parameters of the VLHC based ep colliders (TESLA parameters are given for THERA option).

	VLHC	e-ring	TESLA	JLC/NLC
Beam energy, TeV	50	0.18	0.25	0.25
Circumference or length, km	531	531	10	4.3
Luminosity for ep, $10^{32}\text{cm}^{-2}\text{s}^{-1}$		1.4	3	$\rightarrow 2$
Center of mass energy, TeV		6.0	7.07	7.07
Number of bunches per ring	6000	6000	-	-
Particles per bunch, 10^{10}	12.5	10.1	2	$1\rightarrow 10$
Number of bunches per pulse	-	-	5600	$95\rightarrow 10$
Pulse frequency, Hz	-	-	5	150

Table 2. Future TeV scale lepton-hadron colliders.

	THERA			Linac *	LHC	Linac *	VLHC
	1	2	3	1	2	1	2
E_e , TeV	0.25	0.5	0.8	1	1	0.25	3
E_p , TeV	1	0.5	0.8	7	14	50	50
\sqrt{s} , TeV	1	1	1.6	5.29	7.48	7.07	24.5
L , $10^{31}\text{cm}^{-2}\text{s}^{-1}$	0.4	2.5	1.6	$10\div 100$	$20\div 200$	$20\div 200$	$10\div 100$